Arrowtooth Flounder

By

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Executive Summary

The following changes have been made to this assessment relative to the November 2002 SAFE.

Changes to the input data

1) 2003 survey size composition.

2) 2003 shelf survey biomass point-estimates and standard errors.

3) Estimate of catch and discards through 6, September 2003.

4) Estimate of retained and discarded portion of the 2002 catch.

New Methodology

1) Estimated shelf survey catchability as a function of average annual bottom water temperature.

2) Used observed shelf survey sex ratios as a prior for estimating model population estimates.

Assessment results

1) The projected age 1+ total biomass for 2004 is 696,400 t.

2) The projected female spawning biomass for 2004 is 502,800 t.

3) The recommended 2004 ABC is 114,600 t based on an $F_{0.40}$ (0.28) harvest level.

4) The 2004 overfishing level is 141,500 t based on a $F_{0.35}$ (0.36) harvest level.

	2003 Assessment recommendation for 2004 harvest	2002 Assessment recommendation for 2003 harvest
Total biomass	696,400 t	596,600 t
ABC	114,600 t	112,300 t
Overfishing	141,500 t	139,000 t
F_{ABC}	$F_{0.40} = 0.28$	$F_{0.40} = 0.30$
$F_{overfishing}$	$F_{0.35} = 0.36$	$F_{0.30} = 0.38$

Introduction

The arrowtooth flounder (Atheresthes stomias) is a relatively large flatfish which occupies continental shelf waters almost exclusively until age 4, but at older ages occupies both shelf and slope waters. Two species of Atheresthes occur in the Bering Sea. Arrowtooth flounder and Kamchatka flounder (A. evermanni) are very similar in appearance and are not usually distinguished in the commercial catches. In past years, these species were not consistently separated in trawl survey catches and are combined in this assessment to maintain the comparability of the trawl survey time series. Arrowtooth flounder ranges into the Aleutian Islands region where their abundance is lower than in the eastern Bering Sea. The resource in the EBS and the Aleutians are managed as a single stock although the stock structure has not been studied.

Arrowtooth flounder was managed with Greenland turbot as a species complex until 1985 because of similarities in their life history characteristics, distribution and exploitation. Greenland turbot were the target species of the fisheries whereas arrowtooth flounder were caught as bycatch. Because the stock condition of the two species have differed markedly in recent years, management since 1986 has been by individual species.

Arrowtooth flounder begin to recruit to the continental slope at about age 4. Based on age data from the 1982 U.S.-Japan cooperative survey, recruitment to the slope gradually increases at older ages and reaches a maximum at age 9. However, greater than 50% of age groups 9 and older continue to occupy continental shelf waters. The low proportion of the overall biomass on the slope during the 1988 and 1991 surveys, relative to that of earlier surveys, indicates that the proportion of the population occupying slope waters may vary considerably from year to year depending on the age structure of the population.

Catch History

Catch records of arrowtooth flounder and Greenland turbot were combined during the 1960s. The fisheries for Greenland turbot intensified during the 1970s and the bycatch of arrowtooth flounder is assumed to have also increased. In 1974-76, total catches of arrowtooth flounder reached peak levels ranging from 19,000 to 25,000 t (Table 6.1). Catches decreased after implementation of the MFCMA and the resource has remained lightly exploited with catches averaging 12,300 t from 1977-2003. This decline resulted from catch restrictions placed on the fishery for Greenland turbot and phasing out of the foreign fishery in the U.S. EEZ. Total catch reported through 27 September, 2003 is 11,821 t (well below the 2003ABC of 112,000 t). NMFS Regional Office reports indicate that bottom trawling accounted for 91% of the 2002 catch.

Although research has been conducted on their commercial utilization (Greene and Babbitt 1990, Wasson et al. 1992, Porter et al. 1993, Reppond et al. 1993, Cullenberg 1995) and some targetting occurs, arrowtooth flounder currently have a low perceived commercial value as they are captured primarily in pursuit of other high value species and most are discarded.. The catch information in Table 6.1 reports the annual total catch tonnage for the foreign, JV, and DAP fisheries. The proportion of retained and discarded arrowtooth flounder in Bering Sea fisheries are estimated from observer sampling applied to the 'blend' estimate of reported and observed retained catch as follows:

Year*	Retained	Discarded	Total	% Retained
1985	17 t	72 t	89 t	19
1986	65 t	277 t	342 t	19
1987	75 t	320 t	395 t	19
1988	3,309 t	14,107 t	17,416 t	19
1989	958 t	4,084 t	5,042 t	19
1990	2,356 t	10,042 t	12,398 t	19
1991	3,211 t	18,841 t	22,052 t	15
1992	675 t	9,707 t	10,382 t	7
1993	403 t	6,775 t	7,178 t	6
1994	626 t	13,641 t	14,267 t	4
1995	509 t	8,772 t	9,281 t	5
1996	1,372 t	13,280 t	14,652 t	9
1997	1,029 t	9,024 t	10,054 t	10
1998	2,896 t	12,345 t	15,241 t	19
1999	2,538 t	8,035 t	10,573 t	24
2000	5,124 t	7,805 t	12,929 t	60
2001	4,271 t	6,959 t	11,230 t	62
2002	4,039 t	7,501 t	11,540 t	35

*1990 % retained rate applied to the 1985-89 reported retained DAP catch.

Substantial amounts of arrowtooth flounder are discarded overboard in the various trawl and longline target fisheries. Largest discard amounts occurred in the Pacific cod fishery and the various flatfish fisheries.

Data

The data used in this assessment include estimates of total catch, trawl survey biomass estimates and standard error from shelf and slope surveys, sex-specific trawl survey size composition and available fishery length-frequencies from observer sampling .

Fishery Catch and Catch-at-Age

Fishery catch data from 1970 - September 6, 2003 and fishery length-frequency data from 1978-91 are used in the assessment.

Survey CPUE

The relative abundance of arrowtooth flounder increased substantially on the continental shelf from 1982 to 1990 as the CPUE from AFSC surveys on the shelf increased steadily from 1.6 to 9.9 kg/ha (Fig. 6.1). The overall shelf catch rate decreased slightly to 7.1 kg/ha during 1991 but increased to 9.5 kg/ha during the 1992 bottom trawl survey. The CPUE continued to increase through 1996 to 12.0 kg/ha. These increases in CPUE were also observed on the slope from 1981 to 1986 as CPUE from the Japanese land-based fishery increased from 1.5 to 21.0 t/hr (Bakkala and Wilderbuer 1990). The CPUE declined from10.3 kg/ha in 1997 to 5.7 kg/ha in 1999 and has increased since that time to 7.7 kg/ha in 2002 and 11.4 kg/ha in 2003.

Absolute Abundance from Trawl Surveys

Biomass estimates (t) for arrowtooth flounder from U.S. and U.S.-Japanese cooperative surveys in the eastern Bering Sea and Aleutian Islands region are as follows:

	Eastern Bering Sea			Aleutian Islands
Year	Shelf	Slope	Shelf and Slope combined	
1975	28,000	--	--	--
1979	35,000	36,700	71,700	--
1980	47,800	--	--	40,400
1981	49,500	34,900	84,400	--
1982	67,400	24,700	92,100	--
1983	149,300	--	--	45,100
1984	182,900	--	--	--
1985	159,900	74,400	234,300	--
1986	232,100	--	--	125,700
1987	290,600	--	--	--
1988	306,500	30,600*	337,100	--
1989	410,700	--	--	--
1990	459,200	--	--	--
1991	329,200	28,000*	357,200	37,294
1992	414,000	--	--	--
1993	543,600	--	--	--
1994	570,600	--	--	107,019
1995	480,800	--	--	--
1996	556,400	--	--	--
1997	478,600	--	--	111,557
1998	344,900	--	--	--
1999	243,800			--
2000	340,400	--	--	93,515
2001	408,800	--	--	–
2002	355,100	61,200	416,300	88,700
2003	553,900	--	--	--

*The 1988 and 1991 slope estimates were from the depth ranges of 200-800 m while earlier slope estimates were from 200-1,000 m. The 2002 slope estimate was from sampling conducted from 200-1,200 m.

Although the standard sampling trawl changed in 1982 to a more efficient trawl which may have caused an overestimate of the biomass increase in the pre-1982 part of the time-series, biomass estimates from AFSC surveys on the continental shelf have shown a consistent increasing trend since 1975. Since 1982, biomass point -estimates indicate that arrowtooth abundance has increased eight-fold to a high of 570,600 t in 1994. The population biomass remained at a high level from 1992-97. Results from the 1997-2000 bottom trawl surveys indicate the Bering Sea shelf population biomass had declined to 340,000 t, 60% of the peak 1994 biomass point estimate. The 2002 shelf survey estimate was higher at 355,100 t and increased further to 553,900 t in 2003, near the peak level estimated in 1994.

Arrowtooth flounder absolute abundance estimates are based on "area-swept" bottom trawl survey methods. These methods require several assumptions which can add to the uncertainty of the estimates. For example, it is assumed that the sampling plan covers the distribution of the species and that all fish in the path of the trawl are captured (no losses due to escape or gains due to herding). Due to sampling variability alone, the 95% confidence intervals for the 2003 point estimate are 431,200 – 620,900 t.

Trawl surveys on the continental slope estimate that arrowtooth flounder biomass increased significantly from 1982 to 1985. The biomass estimate in 1988 and 1991 were lower. However, sampling in 1988 and 1991 (200-800 m) was not as deep as in 1985 and earlier years (200-1,000 m). Based on slope surveys conducted between 1979 and 1985, 67 to 100% of the arrowtooth flounder biomass on the slope were found at depths less than 800 m. These data suggest that less than 20% of the total EBS population occupied slope waters in 1988 and 1991, a period of high arrowtooth flounder abundance. Surveys conducted during periods of low and increasing arrowtooth abundance (1979-85) indicate that 27% to 51% of the population weight occupied slope waters.

The eastern Bering Sea continental slope was surveyed in 2002 at depths ranging from 200 - 1,200 meters. The Poly Nor' Eastern bottom trawl net with mud sweep ground gear was the standard sampling net. Surveys conducted in 1988 and 1991 used a Nor' Eastern trawl with bobbin roller gear. Although this survey was deeper than earlier slope surveys, over 90% of the estimated arrowtooth biomasss was located in waters less than 800 meters. The 2002 slope estimate was 61,200 t.

Approximately 751.4 million fish were estimated for the eastern Bering Sea in 2002 with most of the fish (704.9 million) occupying shelf waters and 46.5 million located on the continental slope. The Aleutian Islands region accounted for an additional 119 million arrowtooth flounder.

The combined arrowtooth/Kamchatka flounder abundance estimated from the 2002 Aleutian Islands trawl survey is 88,700 t, a continuation of the stable trend observed in the Aleutian Islands since 1994.

Weight-at-age, Length-at-age and Maturity-at-age

Parameters of the von Bertalanffy growth curve for arrowtooth flounder from age data collected during the 1982 U.S.-Japan cooperative survey and the 1991 slope survey (Zimmermann and Goddard 1995) are as follows:

Sex	Sample size	Age range	L_{inf}	k	t_o
<u>1982 age sample</u>					
Male	528	2-14	45.9	0.23	-0.70
Female	706	2-14	73.8	0.14	-0.20
Sexes Combined	1,234	2-14	59.0	0.17	-0.50
<u>1991 age sample</u>					
Male	53	3-9	57.9	0.17	-2.17
Female	134	4-12	85.0	0.16	-0.81

Based on 282 observations during a AFSC survey in 1976, the length (mm)-weight (gm) relationship for arrowtooth flounder (sexes combined) is described by the equation:

$$W = 5.682 \times 10^{-6} * L ** 3.1028.$$

Maturity information from a histological examination of arrowtooth flounder in the Gulf of Alaska (Zimmerman 1997) indicate that male and female fish become 50% mature at 46.9 and 42.2 cm, respectively.

Analytic Approach

Model Structure

This stock assessment utilizes the AD Modeler Builder software to model the population dynamics of Bering Sea arrowtooth flounder. The model is a length-based approach where survey and fishery length composition observations are used to calculate estimates of population numbers-at-age by the use of a length-age (growth) matrix. The model simulates the dynamics of the population and compares the expected values of the population characteristics to the those observed from surveys and fishery sampling programs. This is accomplished by the simultaneous estimation of the parameters in the model using the maximum likelihood estimation procedure. The fit of the simulation values to the observed characteristics is optimized by maximizing the log(likelihood) function.

The suite of parameters estimated by the base model are classified by three likelihood components:

Data Component	Distribution assumption
Trawl fishery size composition	Multinomial
Shelf survey population size composition	Multinomial
Slope survey population size composition	Multinomial
Trawl survey biomass estimates and S.E.	Log normal

The total log likelihood is the sum of the likelihoods for each data component (see Table 6-6). The model allows for the individual likelihood components to be weighted by an emphasis factor. The number of parameters estimated in the initial stages by the model are presented below:

Fishing mortality	Selectivity	Year class strength	Total
28	14	46	88

The recruitment parameters are comprised of 21 initial ages in 1976 and 25 subsequent age 1 recruitment estimates from 1976-2001. Recruitment is 2002 and 2003 was set at the average from 1976-2000. The difference in the number of parameters estimated in this assessment compared to last year can be accounted for by an additional year (2003) of shelf survey data and fishery catch and constraints on the shelf survey selectivity for large males to have a value of 1.0. In addition, one more parameter is estimated in a later stage to estimate the relationship between bottom water temperature and shelf survey catchability (discussed later).

We assume that the shelf and slope surveys measure non-overlapping segments of the arrowtooth flounder stock. The model was configured with the assumption that the Bering Sea shelf area comprises 87% of the population, calculated from the average proportion of shelf/shelf+slope biomass from the trawl survey time-series. In this assessment we did not attempt to incorporate the Aleutian Islands biomass estimate. In past assessments we placed an emphasis of 5.0 on fitting the shelf survey biomass trend since it was the most reliable source of data to discern arrowtooth flounder abundance. Although this is still true, we changed our modeling approach and placed equal emphasis on all data components for this assessment, and instead explored the relationship between annual bottom water temperature and shelf survey catchability to improve the fit to the shelf survey biomass estimates. As in past assessments, results are still closely linked to fitting the general trend of increasing shelf survey biomass estimates during the 1980s to a present high level, and to fitting the male and female size compositions from the shelf survey (Fig. 6.2).

Parameters Estimated Independently

Catchability

A past assessment (Wilderbuer and Sample 1995) analyzed the value of Q or catchability of the research trawl by examining fits of the models' various likelihood components over a range of fixed Q values. The results indicated Q = 2.0 which suggests that more fish are caught in the survey trawl than are present in the "effective" fishing width of the trawl (ie. some herding occurs or the "effective" fishing width of the trawl may be the distance between the doors instead of between the wingtips of the survey trawl).

Attempts to estimate q for this assessment were again unsuccessful as estimated values always reached the upper bounds placed on the parameter. It may not be possible to obtain reliable estimates of q for this stock since only one sample of age structures have been read for Bering Sea arrowtooth flounder. Q is therefore assumed to be 1.0 for the whole stock with 87% on the shelf and 13% in slope waters.

Examination of Bering Sea shelf survey biomass estimates indicate that some of the annual variability seemed to positively covary with bottom water temperature. Variations in CPUE (Fig. 6.1) were particularly evident during the coldest year (1999) and the warmest year (2003) (Fig. 6.3). The relationship between average annual bottom water temperature collected during the survey and annual survey biomass estimates were modeled to provide an improved fit to the shelf survey biomass, as:

$$SurB_t = qe^{-\alpha T_t} \sum N_{t,a} W_{t,a} v_a$$

where $SurB_t$ is the model estimate of shelf survey biomass in year t, α is a parameter estimated by the model, T_t is the average annual bottom water temperature, $N_{t,a}$ is the number at age for each year and age estimated by the model, $W_{t,a}$ is the weight at age for fish in each year, and v_a is the selectivity at age estimated by the model. The value of q was fixed at 0.87 (as discussed above), retaining the base assumption that 87% of the arrowtooth flounder biomass was located on the continental shelf. Insufficient survey age and fishery information is presently available to estimate q independently as a model parameter (estimates of q converge on the upper bounds placed on the parameter).

Parameters Estimated Conditionally

Year class strengths

The population simulation specifies the number-at-age in the beginning year of the simulation, the number of recruits in subsequent years, and the survival rate for each cohort as it moves through the population calculated from the population dynamics equations (see Table 6-6).

Fishing Mortality

The fishing mortality rates (F) for each age and year are calculated to approximate the catch weight by solving for F while still allowing for observation error in catch measurement. A large emphasis was placed on the catch likelihood component.

Selectivity and sex ratio

Survey results indicate that fish less than about 4 years old (< 30 cm) are found only on the Bering Sea shelf. Males from 30-50 cm and females 30-70 cm are found in shelf and slope waters, and males > 50 cm and females > 70 cm are found exclusively on the slope. Sex specific "domed-shaped" selectivity was freely estimated for males and females in the shelf survey. We assumed an asymptotic selectivity pattern for both sexes in the slope survey.

At the present time there is no directed fishery for arrowtooth flounder in the eastern Bering Sea. Length measurements collected from the fishery represent opportunistic samples of arrowtooth flounder taken as bycatch. This results in sample size problems which make estimates of fishery selectivity unreliable. Also, we felt that a directed fishery would likely target a different segment of the stock. Accordingly, the shape of the selectivity curve was fixed asymptotic for older fish in the fishery since a directed fishery would presumably target on larger fish. This also allowed for a realistic calculation of exploitable biomass from the model estimate of total biomass.

Past estimates of the natural mortality of arrowtooth flounder were assumed to be 0.20. This estimate was used because it is similar to that of other species of flatfish with approximately the same age range as arrowtooth flounder and is the same estimate used by Okada et al. (1980). However, examination of shelf and slope survey population estimates indicate that females are consistently estimated to be in higher abundance than males (Fig. 6.4). This difference was also evident in the Gulf of Alaska from triennial surveys conducted from 1984-96 (Turnock et al. 1998). Possible reasons for the higher estimates of females in the survey observations may be: 1) there is a spatial separation of males and females where males are less available to the survey trawl, 2) there is a higher natural mortality for males than females, 3) there are some sampling problems, or 4) there is a genetic predisposition to produce more females than males.

Since we do not believe that male arrowtooth flounder are less available to the Bering Sea shelf survey sampling trawl than females, differential sex-specific natural mortality was investigated as an alternative model in last years assessment as an explanation of the observed differences in catch sex ratio. Assessment results were based on a model run with female M = 0.2 and male M = 0.28 (Wilderbuer and Sample 2002).

For this assessment, model runs were again made with female natural mortality fixed at 0.2 for a range of values for males. Model runs were evaluated with respect to the estimate of male and female selectivity for the shelf survey and the overall model fit. Initial model runs resulted in the best overall fit at male M = 0.22 with maximum male shelf selectivity estimated at 0.52 for age 7. This resulted in an estimated population with equal numbers of males and females. Subsequent runs indicated that fitting fishery length data degraded the fit to the survey biomass and length composition observations. Since fishery length data were essentially from bycatch during the 1980s and were generally low in sample size, they were given a lower weight (0.25) In addition, a prior was placed on fitting the sex ratio estimated from the trawl surveys, as follows:

$$SRlike = 0.5\left[\frac{SR_{obs} - SR_{pred}}{\sigma_{obs}}\right]^2$$

where SRlike is the sex ratio likelihood component, SR_{obs} is the observed sex ratio in shelf survey trawl surveys from 1982-2003, SR_{pred} is the model predicted sex ratio in the estimated population, and σ_{obs} is the standard error of the observed population sex ratio.

Model runs with this configuration result in the best fit to all the data components (Fig. 6.5) at male M = 0.32 with maximum male shelf survey selectivity estimated at 0.9 for age 8 (28-29 cm fish) and 1.0 for females at age 5 Likelihood values for all the data components are shown below from runs made with male natural mortality rates ranging from 0.25 – 0.34.

	Male natural mortality values									
	0.34	**0.33**	**0.32**	**0.31**	**0.30**	**0.29**	**0.28**	**0.27**	**0.26**	**0.25**
shelf survey biomass	94.00	93.89	93.93	93.83	98.41	102.47	103.07	102.83	104.71	106.20
slope survey biomass	63.76	63.81	64.31	64.89	62.76	62.74	64.25	67.82	71.39	77.02
shelf survey length comp	1426.01	1422.85	1419.34	1416.28	1440.86	1455.15	1459.07	1468.06	1472.14	1481.03
slope survey length comp	637.95	630.51	623.75	617.66	627.38	641.68	632.59	621.50	612.29	604.45
fishery length comp	200.64	200.85	203.40	210.26	445.87	613.32	620.13	640.88	645.48	654.50
recruitment	13.34	13.40	13.56	13.82	13.60	13.27	13.76	14.92	16.23	18.49
catch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
sex ratio likellihood	23.44	26.70	30.41	34.53	29.38	25.00	28.05	30.95	34.85	38.34
total likelihood	2459.14	2452.00	2448.69	2451.27	2718.27	2913.64	2920.92	2946.97	2957.09	2980.04

The run with male M = 0.32 is the preferred run since it provides the best fit to all the data components and is consistent with the hypothesis that differences in sex ratios observed from trawl surveys are the result of differential sex-specific natural mortality and not availability. It may be that the rate of male natural mortality is even higher as it was estimated at 0.35 in the Gulf of Alaska stock assessment, an assessment with age data from three surveys which may provide more precise estimates. These analyses are consistent with our hypothesis that the differences in sex ratios observed in catches of arrowtooth flounder throughout the Bering Sea, Aleutian Islands and the Gulf of Alaska result from differential sex-specific survival rates and are not due to distributional or behavior differences. Although the hypothesis of lower availability for males cannot be ruled out without further research, age data from Gulf of Alaska trawl surveys indicate that males do not live past 14-15 years whereas female arrowtooth flounder have been aged at over 20 years

Model Results

Fishing mortality and selectivity

The stock assessment model estimates of the annual fishing mortality on fully selected ages and the estimated annual exploitation rates (catch/total biomass) are given in Table 6.2. The average exploitation rate has been at a low level, 2%, from 1977-2003 due to the relative undesirability of arrowtooth flounder as a commercial product. Age-specific selectivity estimated by the model (Table 6.3, Fig. 6.6) indicate that arrowtooth flounder are 50% selected by the fishery at about 7- 8 years of age and are fully selected by ages 15 and 13, for males and females, respectively.

Abundance Trend

Model estimates indicate that arrowtooth flounder total biomass increased more than 2.5 times from 1976 to the 1995 value of 823,000 t (Fig. 6.7, Table 6.4). The biomass has declined 15% since then to the 2003 estimate of 703,000 t. Female spawning biomass is also estimated to be at high level, 519,200 t in 2003, also a 15% decline from the 1995 peak level (Table 6.4). Model estimates of population numbers by age, year, and sex are given in Table 5.5.

The model fit to the shelf survey tracks the trend of increasing abundance from 1982 to the high levels since the mid 1990s, but does not fit the high biomass estimates of 1993, 1994, 1996 and particularly 2003. Consideration of the relationship between annual bottom water temperature and catchability improved the fit to the shelf survey biomass and indicated that catchability increases with water temperature, although the relationship does not hold in all years (Fig 6.3). The model indicates an increasing biomass trend on the slope and estimates a higher biomass than the 2002 slope survey estimate (Fig. 6.7). The slope biomass represents a smaller fraction of the total stock and was considered to be poorly estimated by the 1991 survey which is an underestimate due to the reduction in sampling depth relative to earlier surveys.

The model provides reasonable fits to the survey shelf size composition time-series since 1981 for males and females (1989-99), which are shown in the Appendix. Reasonable fits also resulted for slope survey size composition observations. We recognize the need to read age data for BSAI arrowtooth flounder to improve the fit to these survey observations.

Recruitment Trends

Increases in abundance from 1983-95 were the result of 5 strong year-classes spawned in 1980, 1983, 1986, 1987 and 1988 (Fig. 6.8, Table 6.6). Since 1989, recruitment is estimated to be at or below average from 1989-94 and then stronger in 1995 and 1998. The 2001 year class also appears strong from small fish observed in the 2003 survey.

Otoliths for aging arrowtooth flounder have been routinely collected during AFSC surveys in the EBS, but they have been infrequently aged because of higher priority for aging other species. However, an examination of length-frequency data shows that modes formed by age groups 1 to 3 are reasonably well separated so that fish less than 25 cm can be used as a measure of recruitment for age 2 fish; some age 1 fish are also included, but they are poorly recruited to the survey trawls. Population estimates (in millions) for fish less than 25 cm are as follows:

Year	1982	1983	1984	1985	1986	1987	1988	1989	1990
Population estimates	86.1	290.2	57.9	62.4	150.3	94.3	200.6	273.8	105.2

Year	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Population estimates	71.7	79.4	96.8	126.6	75.1	55.6	108.8	93.6	92.1	126.3

Year	2001	2002	2003
Population estimates	164.3	108.8	253.4

Over this 22 year period, population estimates for this size group have averaged 126 million. Above average recruitment been observed in surveys conducted in 1983, 1986, 1988, 1989, 2001 and 2003. Since the estimates primarily represent age 2 fish, the year-classes producing the strong recruitment are 1981, 1984, 1986, 1987, 1992, 1999 and 2001. Estimates of age 2 recruitment from the stock assessment model fits this information in the population simulation and indicates average to above average recruitment for the four years following the large 1986 and 1987 year-classes (Fig. 6.8). Recruitment declined in the early 1990s causing a leveling in the population trend but above average year classes in 1998 and 2001 should contribute to a stable population level in the near future.

Acceptable Biological Catch

Arrowtooth flounder have a wide-spread bathymetric distribution in the Bering Sea/Aleutian Islands region and are believed to be at a high level, primarily as a result of five strong year-classes spawned during the 1980s and minimal commercial harvest. They are currently estimated to be at a stable and high level. **The estimate of 2004 total biomass from the stock assessment model is 694,400 t and the female spawning biomass is estimated at 502,800 t (not including the Aleutian Islands)**.

The reference fishing mortality rate for arrowtooth flounder is determined by the amount of reliable population information available (Amendment 56 of the Fishery Management Plan for the groundfish fishery of the Bering Sea/Aleutian Islands). Equilibrium female spawning biomass is calculated by applying the female spawning biomass per recruit resulting from a constant $F_{0.40}$ harvest to an estimate of average equilibrium recruitment. Year classes spawned in 1977-2001 are used to calculate the average equilibrium recruitment. Using the time-series of age 1 recruitment from 1978-2001 from the stock assessment model results in an estimate of $B_{0.40}$ = 249,100 t. The stock assessment model estimates the 2004 level of female spawning biomass at 502,800 t (B). Since reliable estimates of B, $B_{0.40}$, $F_{0.40}$, and $F_{0.30}$ exist and $B>B_{0.40}$ (502,800 > 249,100), arrowtooth flounder reference fishing mortality is defined in tier 3a. For the 2004 harvest: $F_{ABC} \leq F_{0.40} = 0.28$ and $F_{overfishing} = F_{0.35} = 0.36$ (full selection F values).

Acceptable biological catch is estimated for 2004 by applying the $F_{0.40}$ fishing mortality rate and age-specific fishery selectivities to the projected 2004 estimate of age-specific total biomass as follows:

$$ABC = \sum_{a=a_r}^{a_{nages}} \overline{w}_a n_a \left(1 - e^{-M - Fs_a}\right) \frac{Fs_a}{M + Fs_a}$$

where S_a is the selectivity at age, M is natural mortality, W_a is the mean weight at age, and n_a is the beginning of the year numbers at age. **This results in a 2004 ABC of 114,600 t.**

The potential yield of arrowtooth flounder for 2004 at various levels of fishing mortality (full selection) are as follows:

F level	Exploitation rate	Potential yield
$F_{overfishing}$	0.36	141,500 t
$F_{0.40}$	**0.28**	**114,600 t**

Projected Biomass

A standard set of projections is required for each stock managed under Tiers 1, 2, or 3 of Amendment 56. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Protection Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA).

For each scenario, the projections begin with the vector of 2003 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2004 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2003. In each subsequent year, the fishing mortality rate is prescribed on the basis of the spawning biomass in that year and the respective harvest scenario. In each year, recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments estimated in the assessment. Spawning biomass is computed in each year based on the time of peak spawning and the maturity and weight schedules described in the assessment. Total catch is assumed to equal the catch associated with the respective harvest scenario in all years. This projection scheme is run 1000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

Five of the seven standard scenarios will be used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2004, are as follow ("*max* F_{ABC}" refers to the maximum permissible value of F_{ABC} under Amendment 56):

> *Scenario 1*: In all future years, F is set equal to *max* F_{ABC}. (Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs.)
>
> *Scenario 2*: In all future years, F is set equal to a constant fraction of *max* F_{ABC}, where this fraction is equal to the ratio of the F_{ABC} value for 2004 recommended in the assessment to the *max* F_{ABC} for 2004. (Rationale: When F_{ABC} is set at a value below *max* F_{ABC}, it is often set at the value recommended in the stock assessment.)
>
> *Scenario 3*: In all future years, F is set equal to 50% of max F_{ABC}. (Rationale: This scenario provides a likely lower bound on F_{ABC} that still allows future harvest rates to be adjusted downward when stocks fall below reference levels.)
>
> *Scenario 4*: In all future years, F is set equal to the 1999-2003 average F. (Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC}.)
>
> *Scenario 5*: In all future years, F is set equal to zero. (Rationale: In extreme cases, TAC may be set at a level close to zero.)

Two other scenarios are needed to satisfy the MSFCMA's requirement to determine whether a stock is currently in an overfished condition or is approaching an overfished condition. These two scenarios are as follow (for Tier 3 stocks, the MSY level is defined as $B_{35\%}$):

> *Scenario 6*: In all future years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is overfished. If the stock is expected to be above ½ of its MSY level in 2004 and above its MSY level in 2014 under this scenario, then the stock is not overfished.)
>
> *Scenario 7*: In 2004 and 2005, F is set equal to *max* F_{ABC}, and in all subsequent years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is expected to be above its MSY level in 2016 under this scenario, then the stock is not approaching an overfished condition.)

Simulation results (Table 6.7) indicate that arrowtooth flounder are not currently overfished and the stock is not considered to be approaching an overfished condition. The stock projection at the average exploitation rate for the past 5 years is shown in Figure 6.9.

Ecosystem Considerations

Ecosystem Effects on the stock

1) Prey availability/abundance trends

Arrowtooth flounder diet varies by life stage as follows: Larvae consume plankton and algae, early juveniles consume zooplankton, late juvenile stage and adults prey includes polychaetes, crustaceans, brittle stars, shrimp, herring myctophids and other small fish. Adult arrowtooth larger than 30 cm are mainly piscivorus and consume Pollock as a major portion of their diet. Information is not available to assess the abundance trends of the benthic infauna of the Bering Sea shelf. The original description of infaunal distribution and abundance by Haflinger (1981) resulted from sampling conducted in 1975 and 1976 and has not be re-sampled since. Information on Pollock abundance is available in Chapter 1 of this SAFE report. The populations of arrowtooth flounder which have occupied the outer shelf and slope areas of the Bering Sea over the past twenty years for summertime feeding do not appear food-limited. These populations have fluctuated due to the variability in recruitment success which suggests that the primary infaunal food source has been at an adequate level to sustain the rock sole resource.

2) Predator population trends

As juveniles, it is well-documented from studies in other parts of the world that flatfish are prey for shrimp species in near shore areas. This has not been reported for Bering Sea arrowtooth flounder due to a lack of juvenile sampling and collections in near shore areas, but is thought to occur. As late juveniles they are found in stomachs of Pollock and Pacific cod,; mostly on small arrowtooth flounder ranging from 5 to 15 cm standard length..

Past, present and projected future population trends of these predator species can be found in their respective SAFE chapters in this volume. Encounters between arrowtooth flounder and their predators may be limited as their distributions do not completely overlap in space and time.

3) Changes in habitat quality

Changes in the physical environment which may affect arrowtooth flounder distribution patterns, recruitment success, migration timing and patterns are catalogued in the Ecosystem Considerations Appendix of this SAFE report. Habitat quality may be enhanced during years of favorable cross-shelf advection (juvenile survival) and warmer bottom water temperatures with reduced ice cover (higher metabolism with more active feeding).

Fishery Effects on the ecosystem

1) Arrowtoooth flounder are not pursued as a target fishery at this time and thus have no "fishery effect" on the ecosystem. In instances when arrowtooth flounder were caught in sufficient quantities in the catch that they could be classified as a target, their contribution to the total bycatch of prohibited species is summarized for 2001 and 2002 in Table 14 of the Economic SAFE (Appendix C) and is summarized for 2002 as follows:

Prohibited species	Arrowtooth flounder "fishery" % of total bycatch
Halibut mortality	1.7
Herring	0
Red King crab	0
C. bairdi	<1
Other Tanner crab	2.3
Salmon	< 1

2) Relative to the predator needs in space and time, any harvesting of arrowtooth flounder is not very selective for fish between 5-15 cm and therefore has minimal overlap with removals from predation.

3) The catch is not perceived to have an effect on the amount of large size target fish in the population due to it's history of very light exploitation (2%) over the past 28 years.

4) Arrowtooth flounder discards are presented in the Catch History section.

5) It is unknown what effect the catch has had on arrowtooth flounder maturity-at-age and fecundity.

6) Analysis of the benthic disturbance from harvesting arrowtooth flounder is available in the Preliminary draft of the Essential Fish Habitat environmental Impact Statement.

Ecosystem effects on arrowtooth flounder			
Indicator	Observation	Interpretation	Evaluation
Prey availability or abundance trends			
Benthic infauna	Stomach contents	Stable, data limited	Unknown
Predator population trends			
Fish (Pollock, Pacific cod)	Stable	Possible increases to rock sole mortality	
Changes in habitat quality			
Temperature regime	Cold years arrowtooth catchability and herding may decrease	Likely to affect surveyed stock	No concern (dealt with in model)
Winter-spring environmental conditions	Affects pre-recruit survival	Probably a number of factors	Causes natural variability

***Arrowtooth flounder* effects on ecosystem**			
Indicator	Observation	Interpretation	Evaluation
Fishery contribution to bycatch			
Prohibited species	Stable, heavily monitored	Minor contribution to mortality	No concern
Forage (including herring, Atka mackerel, cod, and pollock)	Stable, heavily monitored	Bycatch levels small relative to forage biomass	No concern
HAPC biota	Low bycatch levels of (spp)	Bycatch levels small relative to HAPC biota	No concern
Marine mammals and birds	Very minor direct-take	Safe	No concern
Sensitive non-target species	Likely minor impact	Data limited, likely to be safe	No concern
Fishery concentration in space and time	Very low exploitation rate	Little detrimental effect	No concern
Fishery effects on amount of large size target fish	Very low exploitation rate	Natural fluctuation	No concern
Fishery contribution to discards and offal production	Stable trend	Improving, but data limited	Possible concern
Fishery effects on age-at-maturity and fecundity	unknown	NA	Possible concern

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Table 6.1. All nation total catch (t) of arrowtooth flounder in the eastern Bering Sea and Aleutian Islands region[a], 1970-2002. Catches since 1990 are not reported by area.

	Eastern Bering Sea				Aleutian Island Region				
Year	Non-U.S. fisheries[b]	U.S. J.V.[c]	U.S. DAH	Total	Non-U.S. fisheries	U.S. J.V.	U.S. DAH	Total	Total
1970	12,598			12,598	274			274	12,872
1971	18,792			18,792	581			581	19,373
1972	13,123			13,123	1,323			1,323	14,446
1973	9,217			9,217	3,705			3,705	12,922
1974	21,473			21,473	3,195			3,195	24,668
1975	20,832			20,832	784			784	21,616
1976	17,806			17,806	1,370			1,370	19,176
1977	9,454			9,454	2,035			2,035	11,489
1978	8,358			8,358	1,782			1,782	10,140
1979	7,921			7,921	6,436			6,436	14,357
1980	13,674	87		13,761	4,603			4,603	18,364
1981	13,468	5		13,473	3,624	16		3,640	17,113
1982	9,065	38		9,103	2,356	59		2,415	11,518
1983	10,180	36		10,216	3,700	53		3,753	13,969
1984	7,780	200		7,980	1,404	68		1,472	9,452
1985	6,840	448		7,288	11	59	89	159	7,447
1986	3,462	3,298	5	6,766		78	337	415	7,181
1987	2,789	1,561	158	4,508		114	237	351	4,859
1988		2,552	15,395	17,947		22	2,021	2,043	19,990
1989		2,264	4,000	6,264			1,042	1,042	7,306
1990		660	7,315	7,975			5,083	5,083	13,058
1991									22,052
1992									10,382
1993									9,338
1994									14,366
1995									9,280
1996									14,652
1997									10,054
1998									15,241
1999									10,573
2000									12,929
2001									13,908
2002									11,540
2003**									11,821

[a]Catches from data on file Alaska Fisheries Science Center, 7600 Sand Point Way N.E., Seattle, WA 98115.
[b]Japan, U.S.S.R., Republic of Korea, Taiwan, Poland, and Federal Republic of Germany.
[c]Joint ventures between U.S. fishing vessels and foreign processing vessels.
**Catch information through 27 September, 2003 (NMFS regional office).

Table 6.2 Model estimates of arrowtooth flounder fishing mortality and exploitation rate (catch/total biomass).

year	Full selection F	Exploitation rate
1976	0.110	0.065
1977	0.072	0.041
1978	0.066	0.037
1979	0.097	0.050
1980	0.132	0.063
1981	0.129	0.056
1982	0.085	0.036
1983	0.096	0.040
1984	0.059	0.024
1985	0.041	0.018
1986	0.035	0.015
1987	0.021	0.009
1988	0.075	0.035
1989	0.025	0.012
1990	0.041	0.019
1991	0.063	0.030
1992	0.027	0.013
1993	0.022	0.012
1994	0.031	0.017
1995	0.018	0.011
1996	0.028	0.018
1997	0.019	0.012
1998	0.029	0.019
1999	0.020	0.014
2000	0.026	0.017
2001	0.029	0.019
2002	0.025	0.016
2003	0.023	0.015

Table 6.3 Model estimates of arrowtooth flounder age-specific fishery and survey selectivities, by sex.

	Fishery		shelf survey		slope survey	
Age	females	males	females	males	females	males
1	0.001	0.006	0.049	0.126	0.000	0.022
2	0.004	0.013	0.167	0.199	0.000	0.036
3	0.010	0.029	0.464	0.304	0.001	0.058
4	0.027	0.063	0.844	0.444	0.008	0.091
5	0.070	0.130	1.000	0.611	0.071	0.142
6	0.171	0.249	0.953	0.770	0.411	0.215
7	0.362	0.425	0.842	0.873	0.863	0.311
8	0.608	0.622	0.726	0.876	0.983	0.427
9	0.809	0.785	0.618	0.779	0.998	0.551
10	0.921	0.891	0.522	0.621	1.0	0.669
11	0.970	0.948	0.438	0.454	1.0	0.769
12	0.989	0.976	0.366	0.311	1.0	0.846
13	0.996	0.989	0.304	0.204	1.0	0.901
14	0.998	0.995	0.252	0.130	1.0	0.937
15	0.999	0.998	0.208	0.081	1.0	0.961
16	1.000	0.999	0.171	0.050	1.0	0.976
17	1.0	1.0	0.140	0.031	1.0	0.985
18	1.0	1.0	0.115	0.019	1.0	0.991
19	1.0	1.0	0.094	0.011	1.0	0.995
20	1.0	1.0	0.077	0.007	1.0	0.997
21	1.0	1.0	0.063	0.004	1.0	0.998

Table 6.4 Model estimates of arrowtooth flounder 1+ total biomass and female spawning biomass from the 2002 and 2003 assessments.

	2003 Assessment		2002 Assessment	
	age 1+ Total biomass	Female Spawning biomass	age 1+ Total biomass	Female Spawning biomass
1976	292,953	211,918	167,756	102,751
1977	278,791	198,411	159,384	96,302
1978	277,535	189,875	162,749	94,366
1979	284,965	182,705	172,207	92,966
1980	292,548	176,372	180,536	90,394
1981	304,751	177,952	192,481	91,497
1982	322,461	188,966	210,174	98,576
1983	353,321	202,221	242,341	110,170
1984	386,392	214,424	279,260	121,895
1985	424,821	244,553	323,816	150,710
1986	468,667	284,558	377,002	190,017
1987	521,727	311,998	440,148	219,913
1988	579,246	343,251	508,824	256,853
1989	629,303	370,729	569,152	292,906
1990	691,430	406,643	641,304	336,917
1991	741,748	451,675	701,399	387,350
1992	771,929	504,319	740,905	441,685
1993	803,002	552,460	780,969	492,118
1994	821,526	584,498	807,618	528,082
1995	823,910	598,516	816,157	547,116
1996	822,382	608,851	817,749	562,438
1997	809,062	605,743	803,520	564,034
1998	797,838	596,615	786,500	558,777
1999	780,431	576,890	756,434	540,877
2000	766,400	565,366	724,719	525,870
2001	749,564	553,529	684,381	505,741
2002	727,472	538,871	637,958	479,703
2003	703,141	529,199		

Table 6.5 Model estimates of arrowtooth flounder population number-at-age, by sex, 1976-2003.

females	numbers at age (1,000s)																				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1976	104,499	62,155	33,145	32,194	50,629	31,569	17,229	12,337	9,997	8,533	7,439	6,555	5,791	5,113	4,490	3,939	3,429	2,978	2,551	2,174	6,992
1977	216,215	85,544	50,868	27,107	26,280	41,131	25,362	13,554	9,446	7,486	6,312	5,473	4,812	4,248	3,749	3,292	2,888	2,514	2,183	1,870	6,720
1978	108,559	177,005	70,019	41,617	22,151	21,408	33,264	20,233	10,623	7,297	5,737	4,820	4,174	3,668	3,237	2,857	2,509	2,201	1,916	1,664	6,546
1979	119,681	88,873	144,885	57,289	34,013	18,052	17,331	26,593	15,915	8,246	5,623	4,406	3,698	3,200	2,812	2,482	2,190	1,923	1,687	1,468	6,293
1980	151,209	97,974	72,737	118,507	46,782	27,659	14,536	13,700	20,525	12,046	6,174	4,190	3,278	2,749	2,378	2,089	1,844	1,627	1,429	1,254	5,767
1981	345,119	123,778	80,176	59,474	96,683	37,950	22,140	11,348	10,354	15,107	8,737	4,450	3,012	2,354	1,973	1,707	1,500	1,324	1,168	1,026	5,040
1982	131,712	282,511	101,293	65,558	48,525	78,444	30,391	17,301	8,590	7,637	10,984	6,313	3,207	2,169	1,694	1,420	1,229	1,079	953	841	4,365
1983	116,542	107,824	231,228	82,861	53,551	39,491	63,291	24,125	13,448	6,563	5,780	8,278	4,750	2,412	1,631	1,274	1,068	924	811	716	3,913
1984	311,613	95,405	88,248	189,131	67,665	43,548	31,802	50,041	18,627	10,183	4,917	4,309	6,161	3,532	1,793	1,212	947	794	687	603	3,441
1985	221,516	255,107	78,094	72,209	154,604	55,172	35,297	25,490	39,532	14,542	7,898	3,802	3,329	4,757	2,727	1,384	936	731	613	530	3,122
1986	200,539	181,352	208,833	63,912	59,055	126,215	44,854	28,473	20,356	31,310	11,465	6,214	2,989	2,617	3,739	2,143	1,088	735	575	482	2,870
1987	541,234	164,180	148,460	170,918	52,278	48,232	102,721	36,264	22,824	16,203	24,825	9,075	4,916	2,364	2,069	2,956	1,695	860	582	454	2,650
1988	268,264	443,113	134,409	121,524	139,859	42,740	39,350	83,479	29,322	18,378	13,017	19,925	7,281	3,943	1,896	1,660	2,371	1,359	690	466	2,490
1989	244,843	219,614	362,690	109,962	99,295	113,904	34,544	31,353	65,291	22,589	14,040	9,908	15,144	5,531	2,995	1,440	1,260	1,801	1,032	524	2,245
1990	168,329	200,454	179,788	296,871	89,969	81,153	92,857	28,027	25,281	52,382	18,072	11,219	7,913	12,093	4,416	2,391	1,150	1,006	1,438	824	2,211
1991	195,409	137,808	164,093	147,138	242,792	73,450	65,979	74,911	22,384	20,026	41,305	14,222	8,822	6,221	9,506	3,471	1,880	904	791	1,130	2,386
1992	167,332	159,974	112,802	134,263	120,262	197,898	59,486	52,795	59,013	17,410	15,466	31,802	10,937	6,781	4,781	7,305	2,667	1,444	695	608	2,702
1993	156,168	136,995	130,963	92,329	109,845	98,273	161,268	48,224	42,513	47,259	13,900	12,332	25,343	8,714	5,402	3,809	5,820	2,125	1,151	553	2,637
1994	94,685	127,856	112,153	107,199	75,548	89,794	80,156	130,988	38,957	34,191	37,915	11,140	9,879	20,299	6,979	4,327	3,050	4,661	1,702	922	2,555
1995	173,013	77,519	104,667	91,795	87,695	61,721	73,132	64,903	105,265	31,114	27,215	30,134	8,848	7,845	16,119	5,542	3,436	2,422	3,701	1,351	2,760
1996	202,737	141,647	63,463	85,679	75,119	71,707	50,374	59,480	52,549	84,914	25,048	21,889	24,228	7,113	6,306	12,958	4,455	2,762	1,947	2,975	3,305
1997	159,508	165,981	115,959	51,945	70,096	61,382	58,430	40,831	47,884	42,068	67,768	19,963	17,436	19,296	5,665	5,022	10,319	3,548	2,199	1,551	5,001
1998	163,420	130,591	135,885	94,922	42,507	57,314	50,094	47,514	33,050	38,612	33,852	54,482	16,044	14,011	15,505	4,552	4,035	8,291	2,850	1,767	5,264
1999	215,172	133,792	106,908	111,221	77,656	34,732	46,694	40,590	38,229	26,438	30,788	26,955	43,358	12,765	11,147	12,335	3,621	3,210	6,596	2,268	5,594
2000	127,204	176,163	109,531	87,511	91,010	63,488	28,337	37,950	32,823	30,787	21,243	24,715	21,629	34,786	10,241	8,943	9,896	2,905	2,575	5,291	6,307
2001	112,942	104,142	144,217	89,654	71,598	74,379	51,751	22,986	30,589	26,320	24,617	16,965	19,727	17,261	27,759	8,172	7,136	7,896	2,318	2,055	9,255
2002	42,900	92,466	85,256	118,041	73,345	58,501	60,596	41,932	18,493	24,467	20,986	19,600	13,500	15,695	13,732	22,083	6,501	5,677	6,282	1,844	8,997
2003	42,900	35,122	75,698	69,784	96,580	59,946	47,695	49,171	33,819	14,841	19,582	16,775	15,660	10,784	12,537	10,969	17,639	5,193	4,534	5,018	8,660

Table 6.5 (cont'd) Model estimates of arrowtooth flounder population number-at-age, by sex, 1976-2003.

males	numbers at age (1,000s)																				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1976	104,499	55,127	26,073	22,461	31,328	17,325	8,386	5,326	3,828	2,898	2,241	1,751	1,372	1,074	837	651	503	387	294	222	420
1977	216,215	75,831	39,972	18,872	16,197	22,426	12,240	5,811	3,611	2,549	1,907	1,466	1,142	893	699	544	423	327	252	191	418
1978	108,559	156,937	55,012	28,964	13,642	11,653	15,996	8,621	4,036	2,479	1,736	1,294	992	772	604	473	368	286	221	170	412
1979	119,681	78,799	113,859	39,870	20,946	9,822	8,324	11,295	6,009	2,783	1,697	1,185	881	675	525	411	321	250	195	150	395
1980	151,209	86,856	57,146	82,445	28,776	15,020	6,962	5,801	7,722	4,044	1,853	1,124	782	581	445	346	271	212	165	128	360
1981	345,119	109,713	62,960	41,337	59,375	20,542	10,555	4,781	3,881	5,057	2,612	1,188	718	499	370	283	220	172	135	105	311
1982	131,712	250,413	79,531	45,546	29,775	42,400	14,445	7,256	3,204	2,547	3,274	1,678	761	459	319	236	181	141	110	86	265
1983	116,542	95,593	181,630	57,608	32,897	21,383	30,141	10,116	4,997	2,176	1,714	2,192	1,121	508	306	212	158	121	94	73	234
1984	311,613	84,578	69,326	131,519	41,579	23,591	15,159	21,008	6,918	3,364	1,450	1,136	1,449	740	335	202	140	104	80	62	203
1985	221,516	226,197	61,368	50,254	95,151	29,964	16,882	10,736	14,708	4,797	2,318	996	779	993	507	229	138	96	71	54	181
1986	200,539	160,814	164,163	44,509	36,399	68,728	21,537	12,047	7,600	10,342	3,358	1,619	695	543	692	353	160	96	67	50	164
1987	541,234	145,591	116,721	119,086	32,250	26,312	49,476	15,410	8,561	5,370	7,280	2,360	1,136	487	381	485	248	112	68	47	150
1988	268,264	392,968	105,692	84,706	86,363	23,356	19,009	35,615	11,048	6,117	3,829	5,185	1,679	809	347	271	345	176	80	48	140
1989	244,843	194,711	285,067	76,579	61,220	62,104	16,645	13,369	24,680	7,562	4,154	2,589	3,499	1,132	545	234	183	233	119	54	127
1990	168,329	177,766	141,342	206,850	55,521	44,310	44,816	11,959	9,558	17,573	5,370	2,946	1,835	2,478	802	386	165	129	165	84	128
1991	195,409	122,202	129,014	102,513	149,820	40,104	31,851	31,984	8,466	6,722	12,305	3,752	2,055	1,279	1,728	559	269	115	90	115	148
1992	167,332	141,842	88,662	93,510	74,144	107,901	28,665	22,514	22,328	5,849	4,613	8,414	2,561	1,402	872	1,178	381	183	79	61	179
1993	156,168	121,488	102,961	64,330	67,786	53,650	77,821	20,575	16,073	15,869	4,145	3,264	5,949	1,810	991	616	832	269	130	56	170
1994	94,685	113,386	88,193	74,717	46,649	49,082	38,744	55,984	14,737	11,472	11,300	2,948	2,320	4,227	1,286	704	438	591	191	92	160
1995	173,013	68,743	82,302	63,984	54,151	33,740	35,370	27,771	39,886	10,447	8,106	7,970	2,078	1,634	2,977	906	496	308	416	135	178
1996	202,737	125,619	49,906	59,731	46,408	39,229	24,389	25,485	19,937	28,549	7,463	5,785	5,685	1,482	1,165	2,123	646	353	220	297	223
1997	159,508	147,193	91,185	36,210	43,298	33,578	28,290	17,502	18,190	14,166	20,225	5,279	4,088	4,017	1,047	823	1,499	456	250	155	367
1998	163,420	115,814	106,857	66,177	26,263	31,365	24,269	20,379	12,562	13,015	10,116	14,427	3,764	2,914	2,863	746	587	1,068	325	178	372
1999	215,172	118,647	84,066	77,529	47,968	19,000	22,613	17,410	14,537	8,918	9,212	7,148	10,187	2,657	2,057	2,020	526	414	754	229	388
2000	127,204	156,228	86,132	61,008	56,226	34,740	13,727	16,279	12,483	10,389	6,360	6,562	5,089	7,250	1,890	1,463	1,437	374	294	536	439
2001	112,942	92,355	113,406	62,498	44,230	40,693	25,066	9,860	11,634	8,883	7,373	4,507	4,647	3,602	5,132	1,338	1,036	1,017	265	208	691
2002	42,900	81,999	67,038	82,280	45,301	31,998	29,338	17,980	7,033	8,259	6,287	5,210	3,182	3,280	2,542	3,621	944	731	718	187	634
2003	42,900	31,147	59,524	48,644	59,655	32,790	23,093	21,081	12,858	5,009	5,867	4,460	3,693	2,255	2,324	1,801	2,565	669	518	508	582

Table 6.6 Estimated age 2 recruitment of arrowtooth flounder (thousands of fish) from the 2002 and 2003 stock assessments.

Year class	2003 Assessment	2002 Assessment
1974	117,282	78,515
1975	161,375	125,830
1976	333,942	215,346
1977	167,671	137,279
1978	184,830	148,807
1979	233,491	197,387
1980	532,924	477,703
1981	203,417	195,949
1982	179,982	173,068
1983	481,304	520,618
1984	342,166	346,391
1985	309,771	328,135
1986	836,081	769,686
1987	414,325	395,112
1988	378,220	375,197
1989	260,010	263,298
1990	301,816	307,287
1991	258,483	258,126
1992	241,242	238,189
1993	146,262	138,320
1994	267,266	220,526
1995	313,174	219,128
1996	246,405	153,903
1997	252,439	146,624
1998	332,391	90,871
1999	196,497	64,592
2000	174,464	

Table 6.7 Projections of arrowtooth flounder female spawning biomass (t), future catch (t) and full selection fishing mortality rates for seven future harvest scenarios.

Scenarios 1 and 2
Maximum ABC harvest permissible

Year	Female spawning biomass	catch	F
2003	519,605	10,652	0.02
2004	502,794	114,656	0.28
2005	402,418	91,335	0.28
2006	322,257	74,118	0.28
2007	255,174	60,500	0.28
2008	209,846	43,319	0.25
2009	195,727	34,621	0.23
2010	197,989	32,141	0.23
2011	206,777	33,353	0.24
2012	216,921	36,297	0.25
2013	225,666	39,302	0.26
2014	232,067	41,667	0.26
2015	236,683	43,326	0.27
2016	239,808	44,409	0.27

Scenario 3
1/2 Maximum ABC harvest permissible

Year	Female spawning biomass	catch	F
2003	519,605	10,652	0.02
2004	507,738	66,837	0.14
2005	451,435	60,759	0.14
2006	396,943	55,756	0.14
2007	343,132	51,001	0.14
2008	301,870	45,941	0.14
2009	281,704	40,887	0.14
2010	275,138	36,843	0.14
2011	276,547	34,656	0.14
2012	282,340	34,142	0.14
2013	289,892	34,556	0.14
2014	297,531	35,318	0.14
2015	304,907	36,139	0.14
2016	311,496	36,889	0.14

Scenario 4
Harvest at average F over the past 5 years

Year	Female spawning biomass	catch	F
2003	519,605	10,652	0.02
2004	512,206	6,777	0.02
2005	501,389	6,726	0.02
2006	482,348	6,647	0.02
2007	455,438	6,490	0.02
2008	433,303	6,230	0.02
2009	425,494	5,921	0.02
2010	425,756	5,669	0.02
2011	430,367	5,558	0.02
2012	437,782	5,586	0.02
2013	446,980	5,698	0.02
2014	457,044	5,850	0.02
2015	467,927	6,017	0.02
2016	478,926	6,184	0.02

Scenario 5
No fishing

Year	Female spawning biomass	catch	F
2003	519,605	0	0
2004	512,736	0	0
2005	507,707	0	0
2006	493,822	0	0
2007	471,420	0	0
2008	453,073	0	0
2009	448,304	0	0
2010	450,876	0	0
2011	457,204	0	0
2012	465,942	0	0
2013	476,272	0	0
2014	487,410	0	0
2015	499,407	0	0
2016	511,580	0	0

Table 6.7 (continued).

Scenario 6
Determination of whether arrowtooth flounder are currently overfished
B35=218,000

Year	Female spawning biomass	catch	F
2003	519,605	10,652	0.02
2004	500,104	141,568	0.36
2005	378,243	105,995	0.36
2006	288,722	81,617	0.36
2007	219,535	58,612	0.33
2008	179,609	39,099	0.27
2009	171,964	32,524	0.25
2010	178,446	31,632	0.26
2011	189,718	34,224	0.28
2012	200,828	38,287	0.30
2013	209,302	41,984	0.31
2014	214,666	44,527	0.32
2015	217,995	46,096	0.32
2016	219,893	46,947	0.32

Scenario 7
Determination of whether arrowtooth flounder are approaching an overfished condition
B35=218,000

Year	Female spawning biomass	catch	F
2003	519,605	10,652	0.02
2004	502,794	114,656	0.28
2005	402,418	91,335	0.28
2006	320,558	91,578	0.36
2007	239,654	70,042	0.36
2008	188,649	43,361	0.28
2009	176,445	34,454	0.26
2010	180,651	32,565	0.27
2011	190,712	34,655	0.28
2012	201,193	38,448	0.30
2013	209,376	42,011	0.31
2014	214,632	44,503	0.32
2015	217,937	46,062	0.32
2016	219,843	46,919	0.32

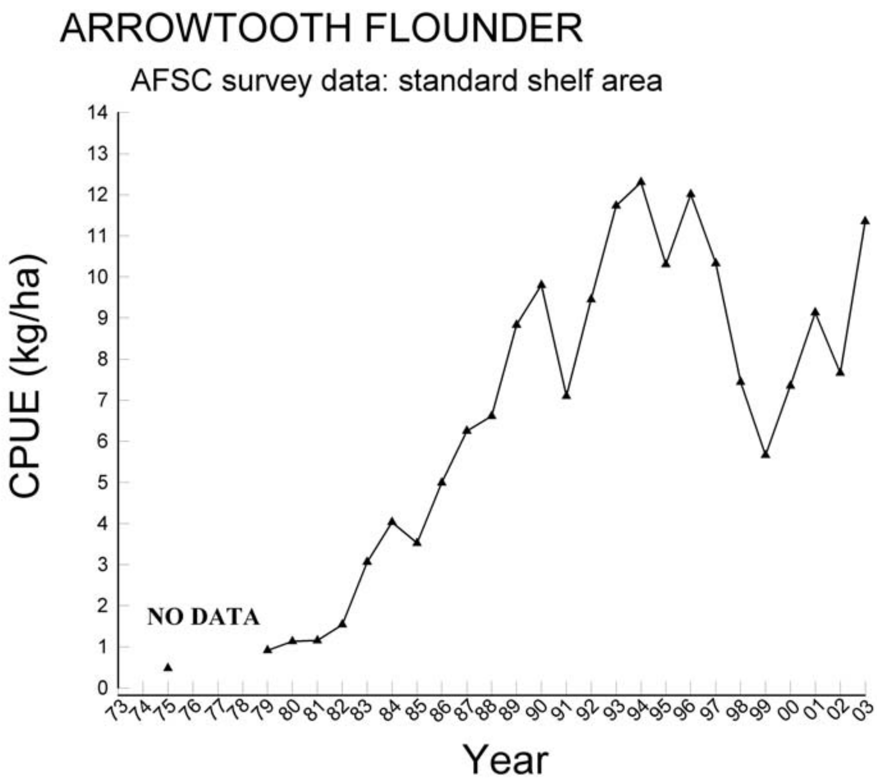


Figure 6.1--Catch per unit effort (CPUE) of arrowtooth flounder on the eastern Bering Sea continental shelf as shown by Alaska Fisheries Science Center (AFSC) survey data.

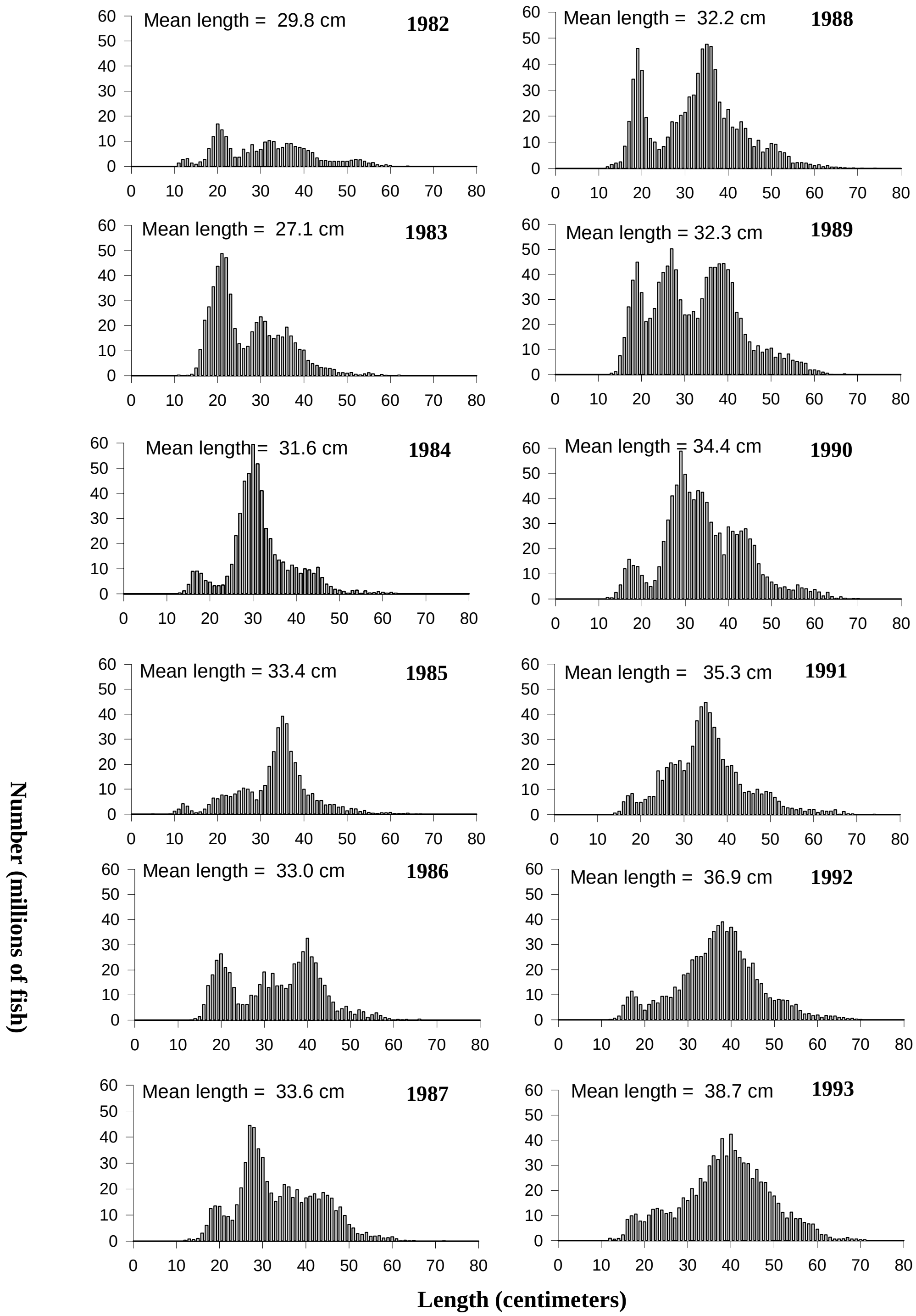


Figure 6.2. Size composition (millions of fish) XXX

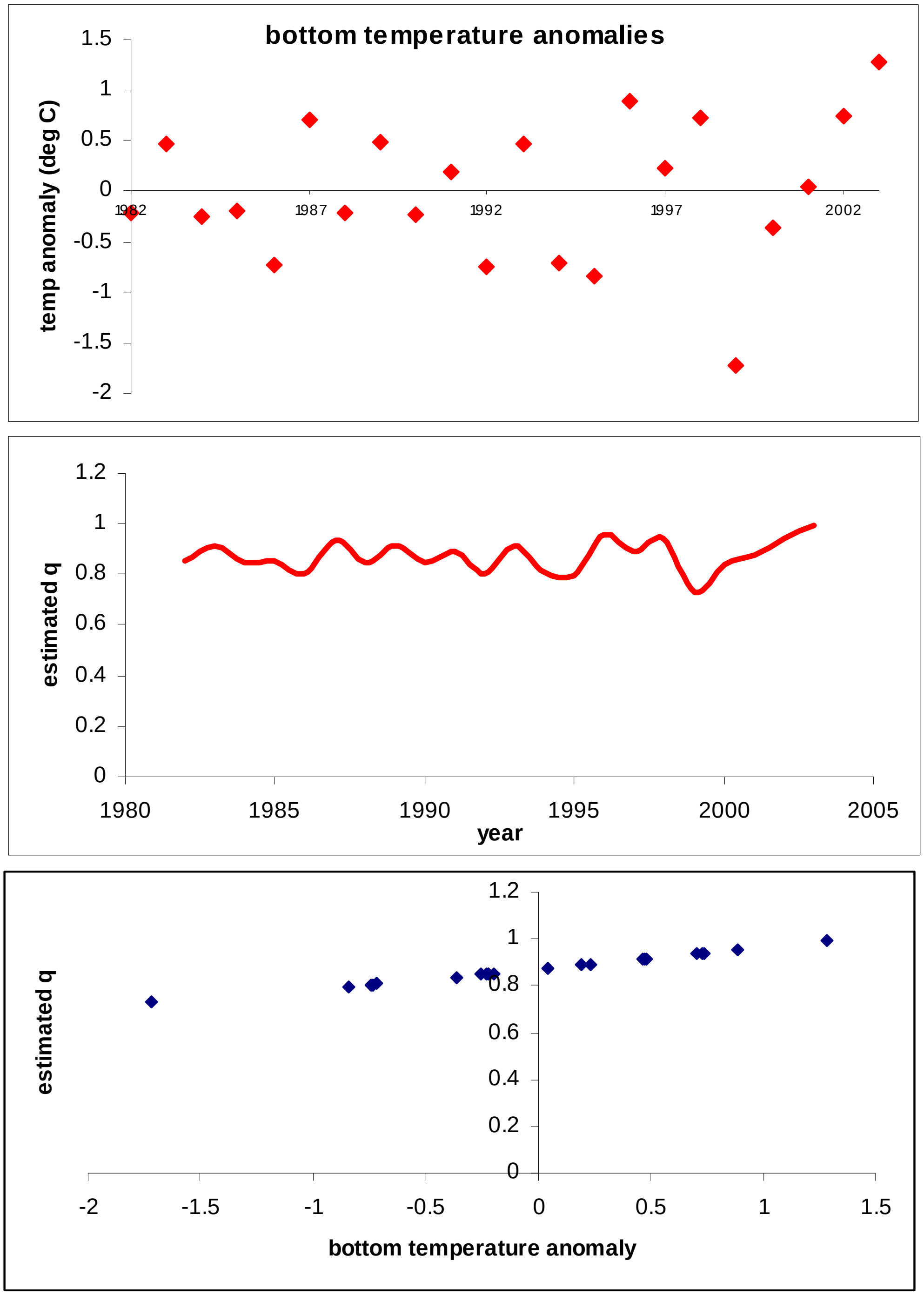


Figure 6.3--Shelf survey annual avg. bottom temperature anomalies (top panel), model estimate of annual shelf survey q due to effect of water temperature (middle panel), and q estimate versus bottom temperature anomaly given the assumption that 87% of the biomass resides on the Bering Sea shelf (bottom panel).

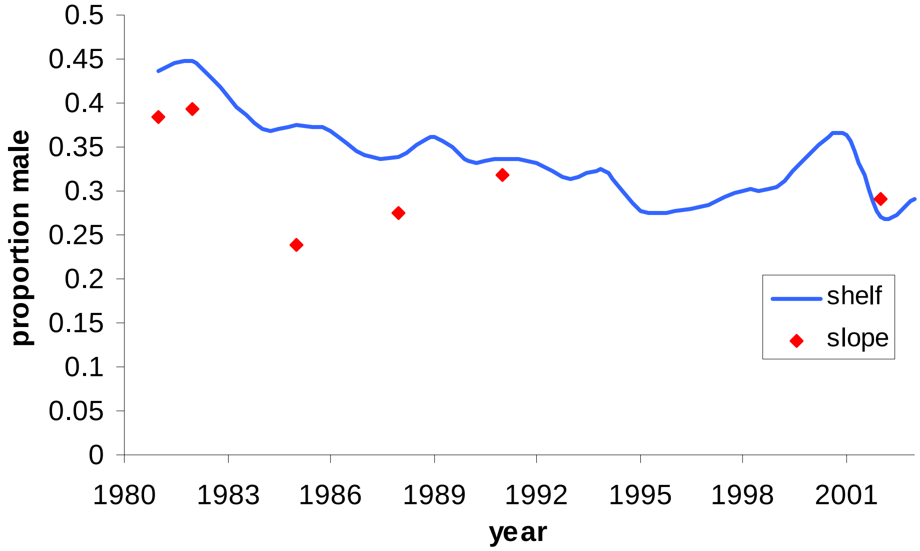


Figure 6.4--Proportion of the estimated male population from Bering Sea trawl surveys on the continental shelf and slope.

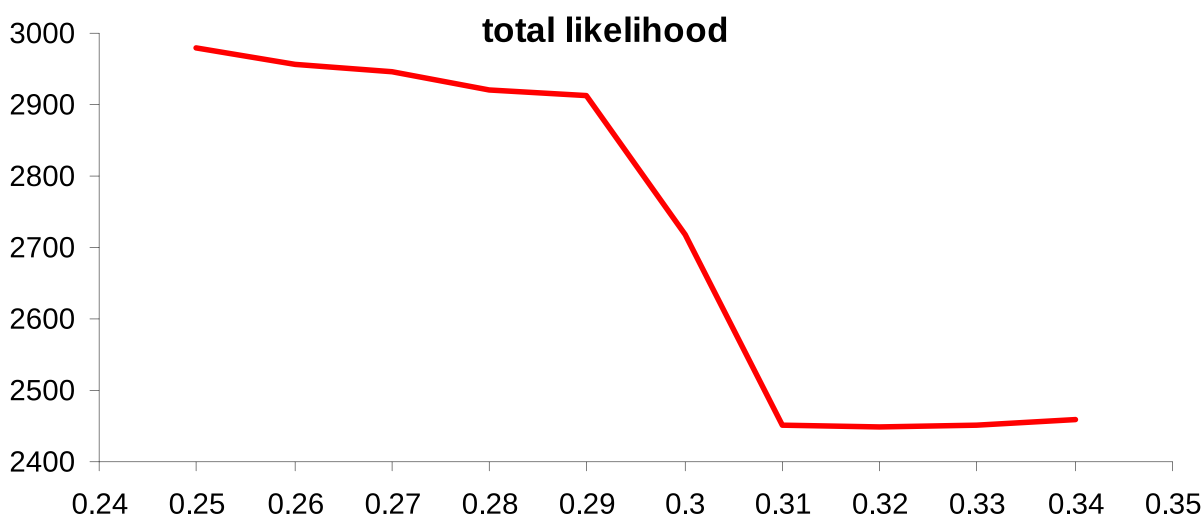


Figure 6.5--Model fit in terms of total -log(likelihood) for a range of natural mortality values for males with females fixed at 0.2.

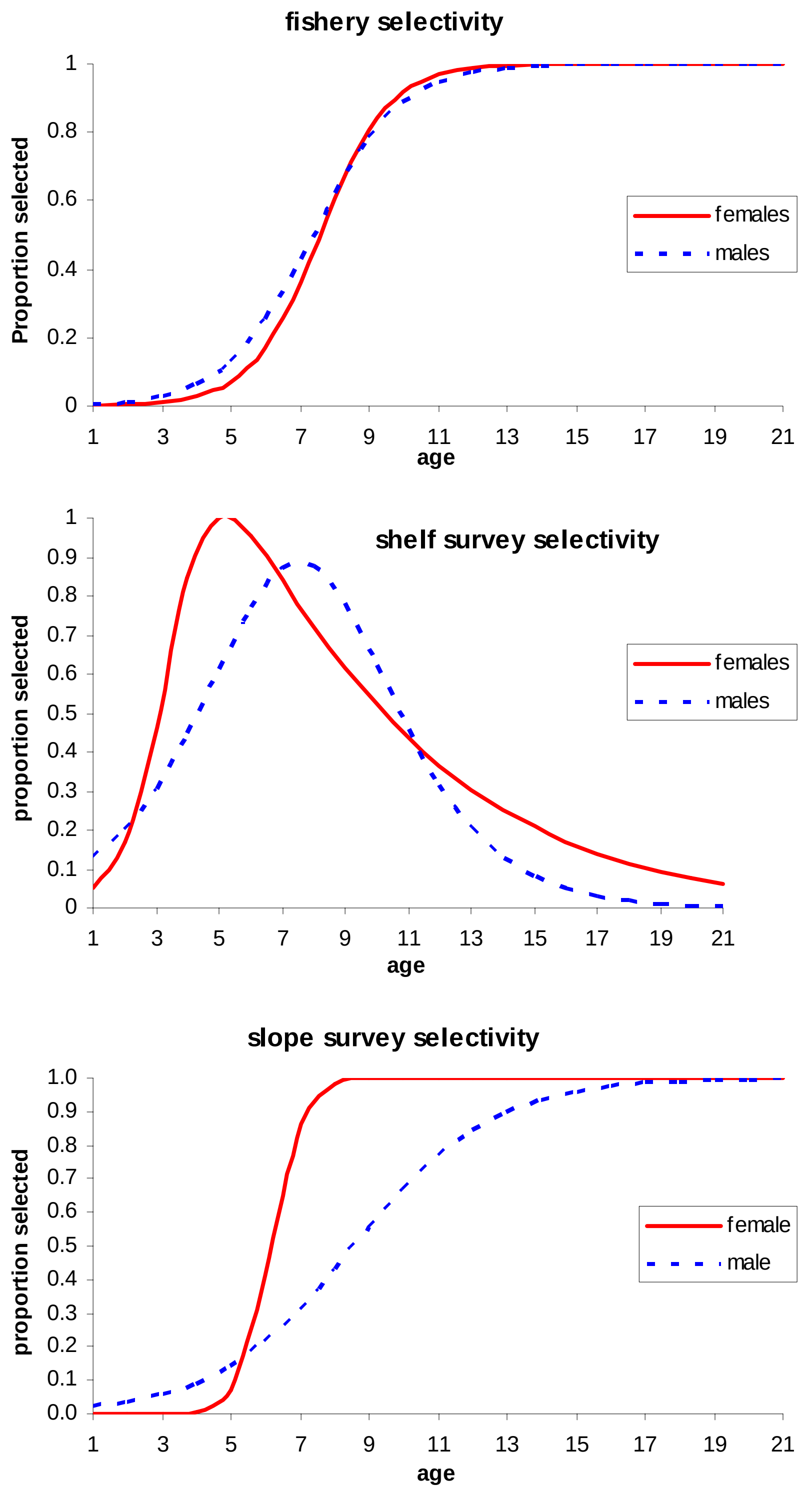


Figure 6.6--Age-specific fishery selectivity (top panel), shelf survey selectivity (middle panel) and slope survey selectivity (bottom panel), by sex, estimated from the stock assessment model.

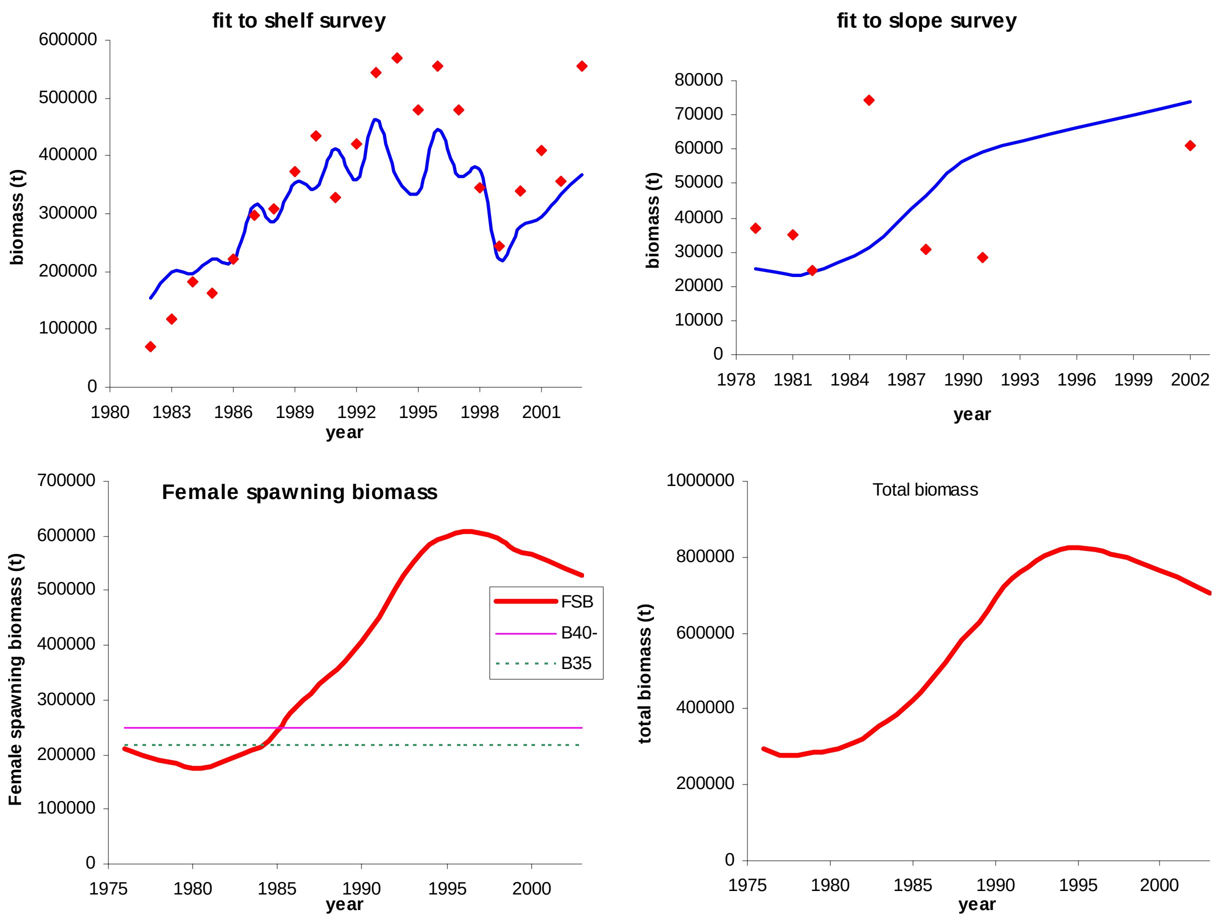


Figure 6.7--Stock assessment model results of the fit to the shelf survey biomass time-series (upper left panel), slope survey biomass (upper right panel), estimate of female spawning biomass with B35 and B40 indicated (bottom left panel) and the estimate of total biomass (bottom right panel).

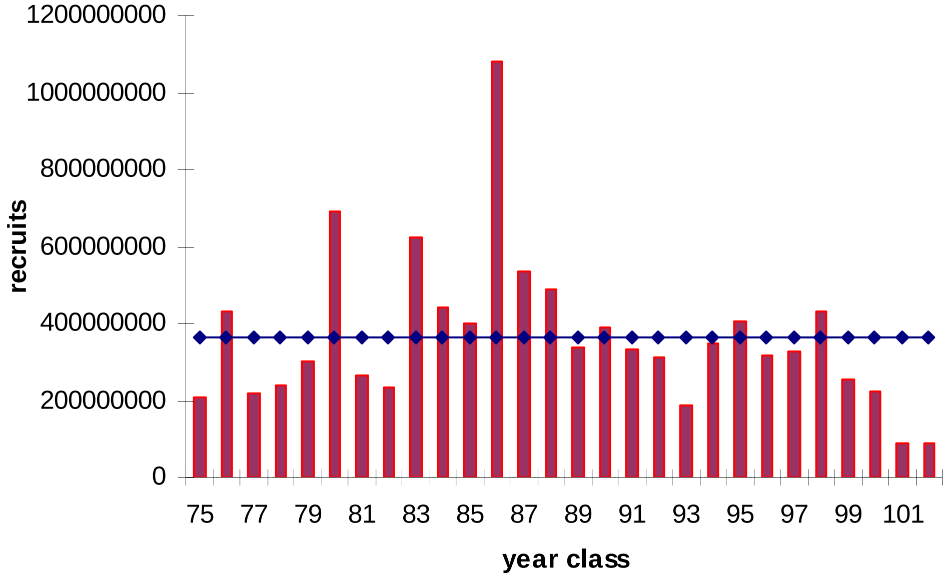


Figure 6.8--Estimates of arrowtooth flounder age 1 recruitment from the stock assessment model.

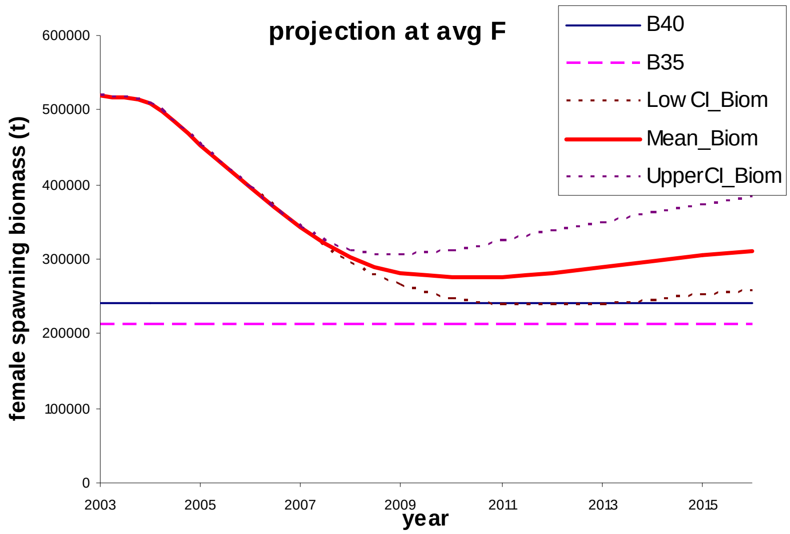


Figure 6.9--Projected female spawning biomass (t) of arrowtooth flounder if future harvest is at the same fishing mortality rate as the past five years.

APPENDIX

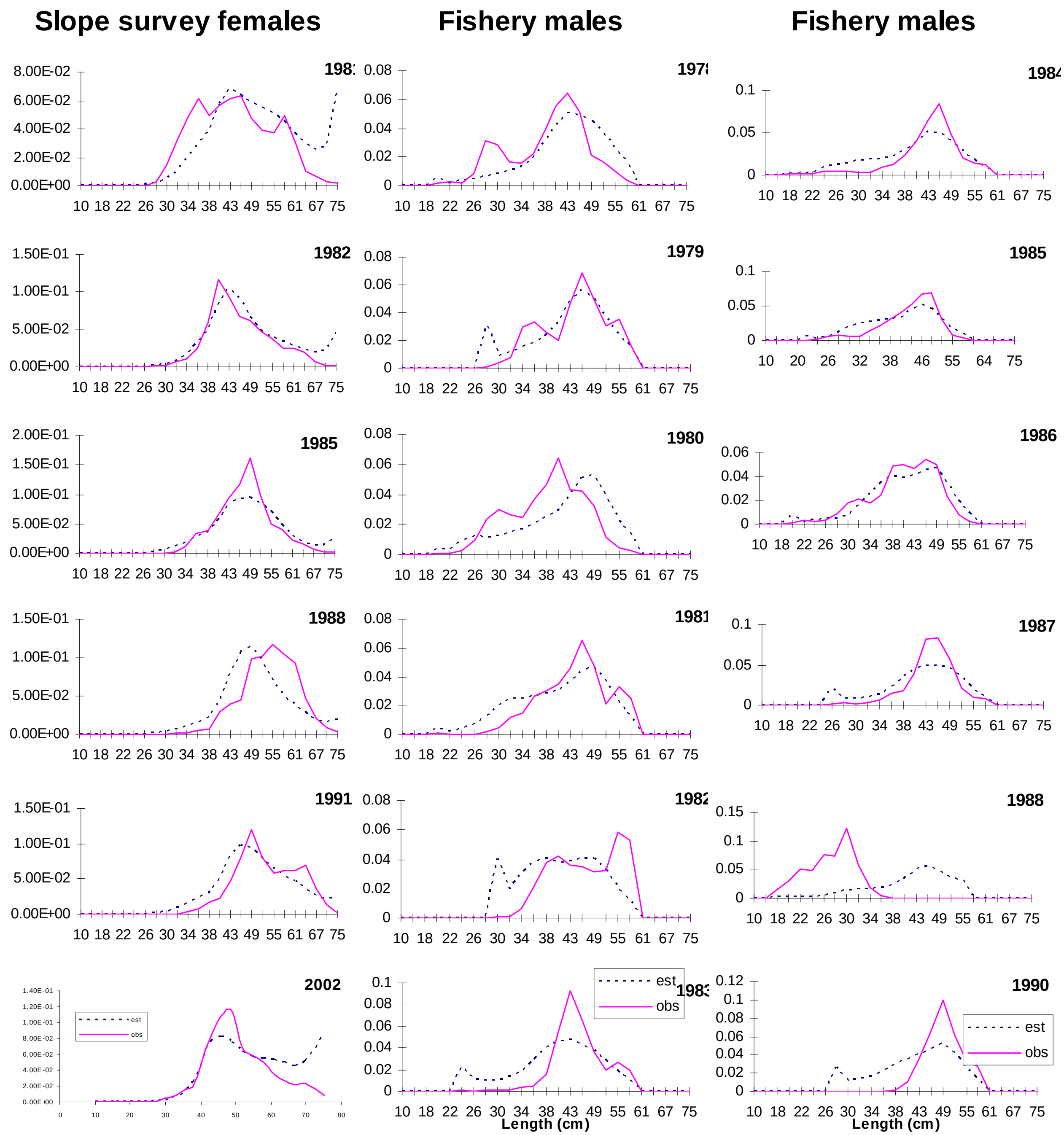
Figures show the fit of the stock assessment model to the time-series of shelf and slope survey size composition data by sex (estimated values are the dotted lines) and the fishery size composition data from 1978-90.

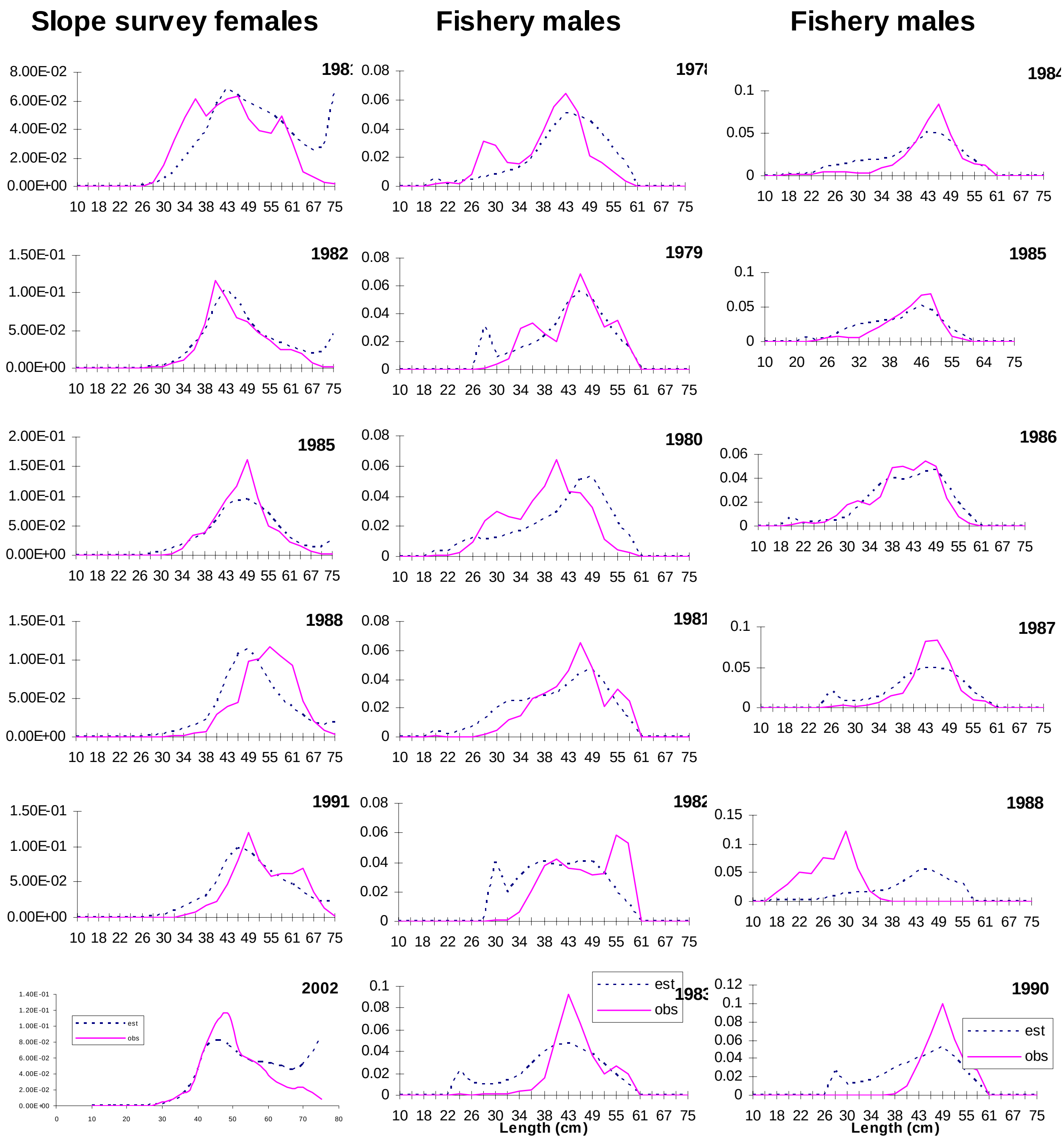
Table of arrowtooth flounder catch during research activities by the Alaska Fisheries Science Center, 1977-2003.

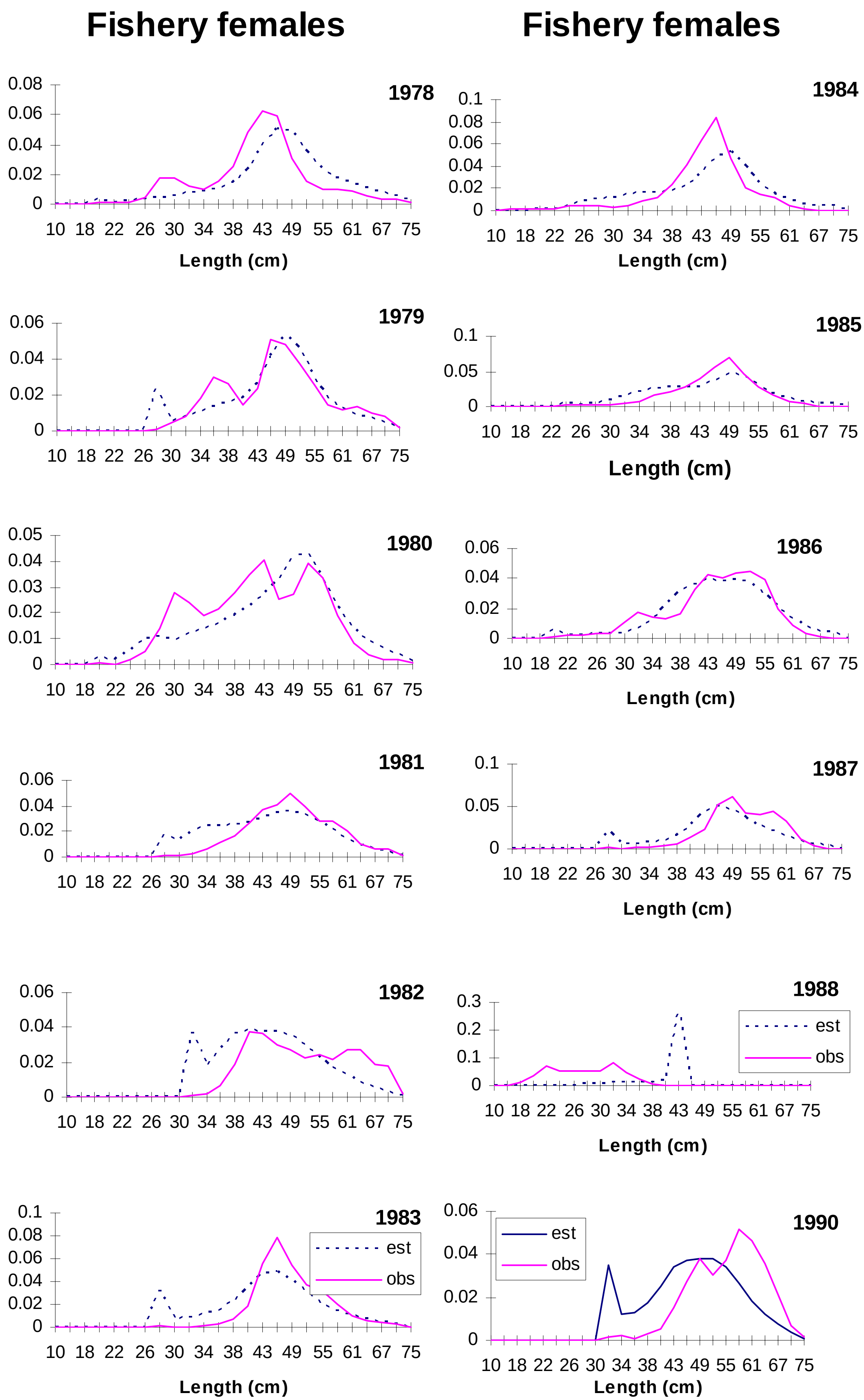

Shelf survey males
Shelf survey males
Shelf survey males
1981
1988
1995
1982
1989
1996
1983
1990
1997
1984
1991
1998
1985
1992
1999
1986
1993
2000
1987
1994
2001
est
obs
Length (cm)
Length cm)
length (cm)

Shelf survey males Shelf survey females Shelf survey females

Shelf survey females **Shelf survey females** **Slope survey males**


Slope survey females
Fishery males
Fishery males
1982
1985
1988
1991
2002
1979
1980
1981
1982
1983
1985
1986
1987
1988
1990
est
obs
Length (cm)
Length (cm)


Slope survey females
Fishery males
Fishery males
1982
1985
1988
1991
2002
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1990
est
obs
Length (cm)
Length (cm)


Fishery females
Fishery females
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1990
Length (cm)
est
obs

Total catch (t) of arrowtooth flounder due to Alaska Fisheries Science Center research activity in the Bering Sea and Aleutian Islands, 1977-2000 and 2003.

Year	Research catch (t)
1977	1.0
1978	3.7
1979	22.5
1980	63.6
1981	48.4
1982	46.6
1983	21.8
1984	6.1
1985	194.1
1986	57.7
1987	9.4
1988	33.7
1989	22.8
1990	18.4
1991	27.5
1992	10.9
1993	16.3
1994	40.7
1995	18.2
1996	17.9
1997	32.3
1998	12.6
1999	9.8
2001	12.8
2002	11.2
2003	18.0

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